Water use and Runoff in the Caloosahatchee Watershed

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ABSTRACT

Water use and runoff in the Caloosahatchee Estuary watershed have been substantially affected by anthropogenic activities during the past 50 years. Construction of the C-43 canal has had the greatest impact on the system, changing the sinuous, shallow river with an extensive flood plain into a large canal and connecting the Caloosahatchee River to Lake Okeechobee. Construction of the canal has allowed extensive drainage of the watershed promoting development of agriculture, primarily citrus and pasture and increased water consumption. The canal provided the opportunity to obtain irrigation water from Lake Okeechobee. Extensive drainage produces high discharge to the estuary potentially damaging the habitat, reducing groundwater recharge and available groundwater, and potentially harming upland and wetland habitats in the watershed. Discharge from Lake Okeechobee when lake stage is too high disrupts the estuary ecosystem. In the past, water from the lake has been available in most years, but has not been available during droughts when the water level in the lake is too low for discharge or is required by other users. However, the availability of lake water for the Caloosahatchee service area is likely to be limited in the future as water is required to satisfy water supply requirements of the lower east coast and the environmental needs of Lake Okeechobee and the Everglades. In the future, innovative means of managing water in the watershed will be necessary to support any additional growth in the region and protect the estuary.

INTRODUCTION

The Caloosahatchee watershed occupies the southern extent of the Charlotte Harbor Estuary Basin (Fig. 1). This is a region of expanding urban and agricultural development with increasing demands on the water resources, both for water use and for flood protection. At the same time, there has been increasing concern for protecting the environment. The demand for water and flood control has resulted in a distortion of the timing and volume of freshwater runoff entering the estuary. A primary environmental concern is the requirement of reasonable freshwater discharge to the estuary; minimum flow of freshwater to the estuary is required to supply necessary nutrients and to prevent excessively high salinity. A reduction in unnaturally high flows is required to avoid reducing salinity to very low levels that are not characteristic of historic hydroperiods. Another environmental concern is protection of wetlands from excessive groundwater draw down due to drainage and pumping from groundwater for irrigation. A first step in understanding these water allocation issues is the development of a water budget for the watershed. This paper will describe the important features of the watershed, the water budget for the estuary from the watershed, and the potential impact of future land use on the discharge to the estuary.

WATERSHED

The Caloosahatchee watershed forms a shallow trough 36 km wide and 110 km long that drains from Lake Okeechobee to the Gulf of Mexico. The longitudinal profile of the river exhibits a gradual drop of 6 m NGVD at the lake with most of elevation loss below old Lake Flirt (Fig. 1). The land slopes from a high of 23 m elevation from the north side to the river and from 13 m elevation on the south to the river. Formed under a marine environment, most of the shallow geologic materials are limestone, marls, silts, clays, shell, sand, and gravel and mixtures of these (Parker et al., 1955; Boggess and Watkins, 1986). Limestone is near the surface west of LaBelle and occurs as outcrops along an east-west line south of LaBelle. The soils are a mix of sandy spodosols throughout most of the watershed with loams found west of LaBelle. Soils in the Everglades Agricultural Area on the far eastern end of the watershed are primarily muck.

The climate of the region is wet subtropical with 75 percent of the precipitation occurring during the summer wet season. The watershed receives approximately 130 cm of rain annually (Table 1). Annual rainfall ranges from 60 to 200 cm (SFWMD, 1994c). There is slightly greater annual rainfall volume along the coast than inland, but this difference is not significant compared to the high year-to-year variability. There is a high spatial variability in daily rainfall due to the localized nature of convectional storms. There is a slight, but not significant, increasing trend in rainfall of 0.15 cm yr^{-1} over the period 1972 to 1994.

The groundwater resources in the watershed are limited. The watershed is underlain by three aquifer systems: the surficial aquifer system (SUS), sandstone, and the Floridan system (Wedderburn et al. 1982). The SUS, which is a combination of the water table aquifer (0-25 m) and the lower Tamiami formation (6-60 m), provides useable water in the region east of LaBelle. Although these aquifers can be highly productive, the yield is highly variable spatially, and are not a dependable sources of water for agriculture (Smith and Adams, 1988). West of LaBelle, groundwater is too mineralized from dissolution of the marine sediments for agricultural use (SFWMD, 1994c). Several major municipal well fields in Lee County draw water from the sandstone aquifer. Urban wells along the coast obtain water from the Floridan, however, this groundwater is highly mineralized and requires reverse osmosis for use.

HISTORY

The hydrology of the Caloosahatchee watershed has been strongly affected by land and canal development. In pre-development times, the Caloosahatchee River was a smaller sinuous river extending from Beautiful Island to Lake Flirt. East of Lake Flirt, there only was sawgrass marsh extending to Lake Okeechobee. The Caloosahatchee River was connected to Lake Okeechobee early in the 1800s by a small canoe trail used by native Americans. In the 1880s, the Disston canal was dug from Lake Flirt to Lake Okeechobee to provide a navigable channel for steamboats from Lake Kissimmee through Lake Okeechobee to the Gulf of Mexico (COE, 1957). The channel was enlarged to a 2 m depth and a 30 m width during the period 1910 to 1930, and three locks were constructed along the canal in 1918 to improve navigation.

By the 1930s, there was pressure for drainage projects that would allow land development in the watershed. Analysis of flood control showed that there was good drainage downstream of Hendry County but insufficient drainage east of LaBelle (Hills, 1927). The landscape was too flat and the river channel provided little conveyance capacity resulting in prolonged inundation; for example, floods in the 1920s left water 2 m deep in LaBelle. Hills (1927) recommended that a long, low dam be created near Ortona to divert runoff towards the Everglades and relieve flooding. Moore Haven and Ortona locks were completed in 1937, and the canal was straightened and deepened in 1937, 1941, and 1966 (Fan and Burgess, 1983). Severe floods in 1948, 1949, and 1953 resulted in construction of the current canal (COE, 1957). The current channel was created to carry a maximum discharge of 120 m^3 s^{-1} from Lake Okeechobee. The channel, designated C-43, was designed to remove runoff to reduce prolonged inundation, accommodate regulatory discharges from Lake Okeechobee, and provide a navigable channel. The project was completed in 1966 with the Franklin Lock and Dam structure (S-79), which was designed to control water by reducing salt water intrusion into the main channel, provide a freshwater head to reduce saltwater intrusion into the water table aquifer, and to maintain a higher water table in the lower region of the watershed (COE, 1957).

Following dredging of the C-43 Canal, several private, water control districts (WCDs) were established to provide drainage in the watershed. These WCDs include those developed for both agricultural and urban land. All of the land on the south side of C-43, excepting urban land immediately adjacent to it, is in one of several WCDs. These districts have constructed drainage canals, water level controls to control drainage, and in many cases, pumps to provide irrigation water for agriculture.

West of LaBelle, WCDs manage water on land away from C-43 but not immediately adjacent to the canal. This has produced a situation where several large drainage canals discharge into small native streams near the river; this causes flows that exceed the conveyance capacity of those streams and produce severe floods. This was observed following high rainfall in the summer of 1995. The land has been over-drained to permit development and few storm water detention/retention areas have been constructed to reduce downstream flooding.

LANDUSE

Land use in the Caloosahatchee watershed has changed from a pre-development mosaic of sloughs, wet prairies, and pine flatwoods to agriculture and urban land (Fig. 2). Urban land has developed along the estuary shoreline at Ft. Myers and along the river since the 1870s. Less than one percent of the watershed was urban in 1950, but urban land now occupies 25 percent of the estuary watershed and 8 percent of the total area. There is another 20 percent of the estuary watershed that exists as open-urban land. In 1957, urban and agricultural land combined occupied less than 2 percent of the watershed (Mierau et al. 1974). By 1977, agriculture occupied 50 percent of the watershed with a compensating reduction in range/scrub land (Fan and Burgess, 1983).

The eastern portion of the Caloosahatchee watershed was a sawgrass marsh extending from Lake Flirt to Lake Okeechobee with wet prairie to the south and pine flatwoods to the north. This area was subject to prolonged flooding prior to development. Although beef cattle pasturing has been in southwest Florida for 300 years, intensive agriculture was not a major landuse until large-scale drainage projects were constructed. Citrus production has grown significantly since the 1970s when freezes killed groves in north and central Florida. The areas of citrus and sugar cane are expected to double over the next 15 years (SFWMD, 1994c).

WATER USE

With the increased development in the watershed, water use has become a significant issue. Urban Lee County, agriculture, and the environment are the three major water users in the watershed (SFWMD, 1994a). Water use demand for 1990 was $94 \times 10^{6}\ m^{3}\ yr^{-1}$ for the 2-in-10 dry year, which is the expected volume of water that would be required two out of every ten years (SFWMD, 1994c). The water supply is limited, particularly during the droughts and the annual dry season. The urban users are located primarily in the lower end of the watershed, associated with the cities of Ft. Myers, Cape Coral, and urban Lee Co. These cities obtain their water from a combination of surface water and groundwater, which is recharged from the river. Cape Coral has an independent water supply system that obtains water from the Floridan aquifer, and it has a complete water reuse system. The urban demand is expected to double during the next twenty years (Table 1).

Agriculture uses water for irrigation that supplements local rainfall. The allocation is based on the available water and the crop requirements. Supplemental water replaces a combination of evapotranspiration and seepage losses from the conveyance system. The land owner is allocated groundwater or river water to provide supplemental irrigation. Water from Lake Okeechobee is used to provide 94×10^{6} m^{3} yr^{-1} irrigation water to 135,000 ha: 40 percent of the watershed. The most critical water requirements are in April and May when the evapotranspiration demand is high due to rapid crop growth and the lack of cloud cover.

Native ecosystems are the other major users of water in the watershed. Although not explicitly considered in the past, both upland ecosystems and the estuary are important water users. The estuary requires a minimum flow, estimated to be 270×10^{6} m^{3} yr^{-1}, to avoid hyper-saline conditions that are detrimental to juvenile fish and other organisms (Chamberlain et al. 1997). Daily discharge should be in the range 8.5 to 23 m^{3} s^{-1} (300-800 cfs). Discharge should not exceed 70 m^{3} s^{-1} (2500 cfs). At high discharge rates, freshwater extends further into the estuary reducing salinity to levels that harm juvenile fish. Wetlands, both sloughs and isolated wetlands, also require the appropriate hydroperiod to remain viable wetland habitats (Duever, 1988).

DISCHARGE and RUNOFF

There are four sources of discharge to the Caloosahatchee Estuary: Lake Okeechobee, the Everglades Agricultural Area (EAA), the Caloosahatchee River watershed, and Estuary watershed. Excess runoff water from the EAA drains into the Caloosahatchee Canal through the S-235 structure near the lake (Fig. 1) and through two privately owned structures at Lake Hicpochee. Although this storm water runoff normally drains south into the Everglades or is back-pumped into Lake Okeechobee, the water can drain into the Caloosahatchee watershed if water levels are high.

The primary source of water to the estuary comes from the river watershed. The river drains 344,000 ha, divided into the East Caloosahatchee basin (ECAL) that drains to the canal between the Moore Haven Lock and spillway (S-77) and the Ortona Lock and Spillway (S-78), and the West Caloosahatchee basin (WCAL) that drains to the canal between Ortona and the Franklin lock and dam structure (S-79) (Fig. 1). Runoff from WCAL is slightly higher than runoff from ECAL (Table 1) indicating the greater flow attenuation in ECAL due to the flatness and thick, sandy soils (Fan and Burgess, 1983). Average annual discharge is log-normally distributed and the median values are presented as the better estimator of the expected annual values (Table 1). The extreme values for discharge are given as the 2-in-10 year values for both dry years and wet years. The 2-in-10 year estimates often are used to describe substantially wet or dry years. This is a level of risk that is often used in water resources analysis (SFWMD, 1994b). Surface water inflow from Caloosahatchee River tributaries delivers 53 percent of the river flow, while the remaining flow comes from groundwater seepage. There is a high variability in annual runoff volume reflecting the high variability in rainfall.

The Caloosahatchee Canal receives discharge from Lake Okeechobee for flood control and water supply. Regulatory discharge via C-43 (Table 1), to lower lake stage for flood protection, is 37% of total surface water discharge from Lake Okeechobee (Fan and Burgess, 1983). In wet years this has resulted in discharge as great as the total runoff from the watershed. This excessive discharge primarily from Lake Okeechobee, which is typically concentrated over a few months during the dry season, has had a detrimental impact on the health of the estuary (Chamberlain and Doering, 1997). The high discharge reduces the salinity in the estuary to very low levels which endangers juvenile fish.

Water is also released to control algal blooms in the river (Miller et al., 1982). At low flow, algal blooms develop in the canal between S-78 and S-79, producing poor drinking water quality for Ft. Myers and Lee County water supplies. Water is released from the lake to flush this water out of the river. Water also is released to push salt water out of the river section that has entered through the locks. This salinity approaches maximum levels as defined by federal drinking water standards, at the fresh water intakes. However, flushing of the river reach is generally ineffective for reducing salinity (Boggess, 1972). Because of higher density, the saltwater remains at the bottom of the channel and the freshwater flows along the surface at moderate flow rates. It requires high flow rates to generate sufficient turbulence to mix the saltwater with the freshwater and flush the salinity out of the river. The high flow rates may damage the estuary and require water which is necessary for other uses.

The estuary also receives runoff from the watershed adjacent to the estuary with approximately one-third of the watershed discharges to the estuary downstream of S-79. This includes Telegraph swamp, a portion of Orange River, several small streams along the estuary, and drainage ditch runoff from urban Lee County. Discharge from urban Lee County drains into the estuary through several ditches where runoff is controlled by discharge structures (Johnson Eng., 1992); there are no available data on this runoff .

DISCUSSION

Determining the native, pre-development annual runoff for the watershed is difficult, because the watershed has been substantially altered by development, ditching, and dredging, and flow records prior to construction of C-43 are not available. However, in comparison with runoff rates from the less altered Myakka and Peace River watersheds in the northern portion of the Charlotte Harbor region, average annual runoff is 20 percent higher in the Caloosahatchee (Hammett, 1990). The increased runoff indicates one probable impact of canal construction.

In 1994, SFWMD completed the Lower West Coast Water Supply Plan that proposed a strategy for ground water management in the Caloosahatchee watershed (SFWMD, 1994a). Based on the large component of unmet future water supply needs, it was recommended that several steps should be taken to increase water supply. This included development of new sources, in particular, deep ground water and water reuse for urban areas. The new water sources would be supported by development of additional storage such as aquifer storage and recovery systems and storage in the Caloosahatchee watershed. These facilities may include reservoirs, on-site retention, and underground storage. The water supply plan pointed out the need to improve the efficiency of irrigation systems. The plan indicated that it would be necessary to develop improved planning and regulatory strategies for minimum flows and levels to protect wetlands and the downstream estuary.

The SFWMD is developing a regional water supply plan for the lower east coast of Florida that includes allocation of water from Lake Okeechobee (SFWMD, 1997). This plan evaluates the surface water issues related to the Caloosahatchee Watershed. With increased urban and agricultural growth in south Florida coupled with the requirement of additional flow from the lake to the Everglades, there will be less water available from Lake Okeechobee for water supply, and it is likely that regulatory discharges will decrease. In normal years runoff may be sufficient to meet demand, but it likely will be inadequate during drought years (SFWMD, 1997). When water is unavailable from the lake, water users will have to depend on local supplies. The local supplies may include surface water or shallow groundwater reservoirs to satisfy unmet water supply needs and modulate discharge to the estuary.

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LIST OF FIGURES

Figure 2. Major landuse types in the east Caloosahatchee basin (ECAL), the west Caloosahatchee basin (WCAL), and the direct Caloosahatchee Estuary watershed (Estuary). Land use for 1955 and 1972 from Mierau et al. (1974). Landuse for 1988 and 1994 from South Florida Water Management District GIS database.

Table 1. Annual rainfall, runoff and water use demand in the Caloosahatchee River watershed. The period of record was 1972 to 1994. Rainfall and discharge were obtained from the South Florida Water Management DBhydro database. Water use demand estimates were obtained from the Lower West Coast Water Supply Plan (SFWMD, 1994c). The 2-in-10 dry and 2-in-10 wet values refer to expected frequency of droughts and floods. These values are equivalent to 20th and 80th percentiles.

	Median	2-in-10 dry	2-in-10 wet
Rain (cm)	120	95	140
Lake Okeechobee Discharge			
Regulatory ($10^6 m^3$)	69	3	830
Water Supply ($10^6 m^3$)	94	66	124
Watershed Runoff			
S-78 discharge ($10^6 m^3$)	350	225	475
ECAL Basin runoff (cm)	36	21	46
S-79 discharge ($10^6 m^3$)	870	500	1,050
WCAL Basin runoff (cm)	38	22	45
Water Use Demand			
Urban-			
1990 estimation ($10^6 m^3$)	17	--	--
2010 projection ($10^6 m^3$)	33	--	--
Agriculture -			
1990 estimation ($10^6 m^3$)	76	--	--

2010 Projection ($10^6 m^3$)	110	--	--
Estuary (Chamberlain et al. 1997)			
Minimum flow ($10^6 m^3$)	270	--	--

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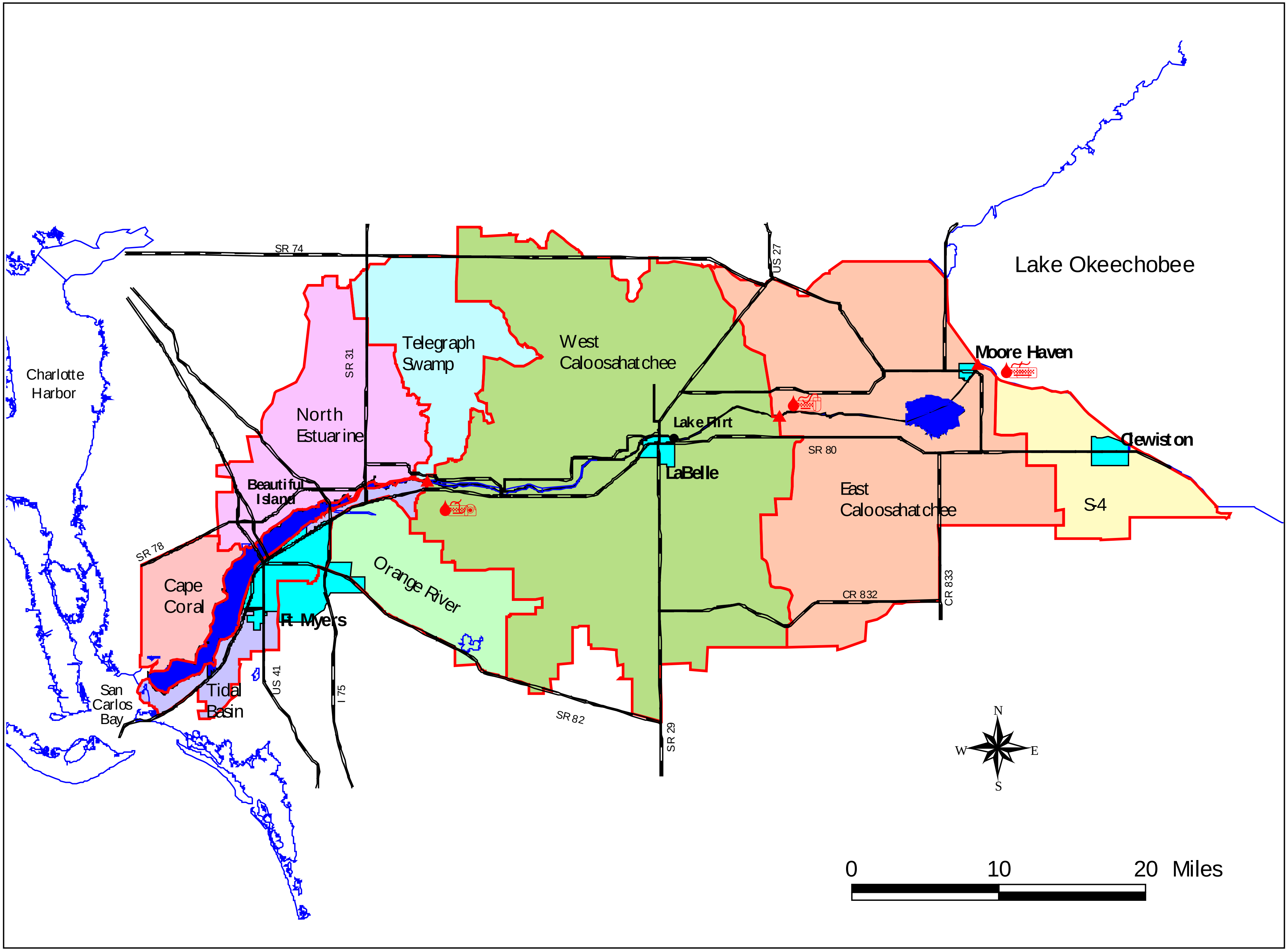
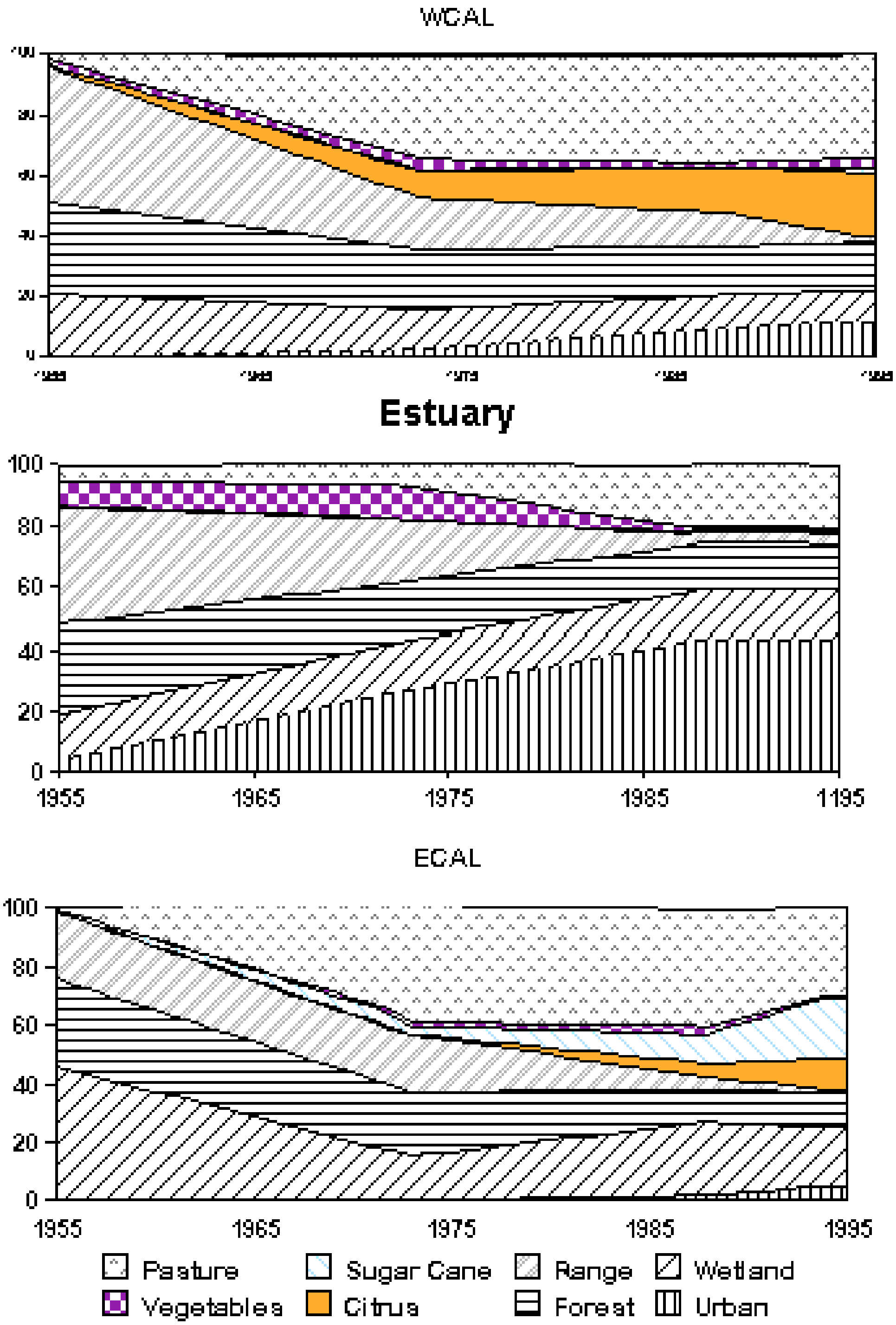


Fig. 8 Caloosahatchee River Watershed.

Fig. 2.


WCAL
Estuary
100
80
60
40
20
0
1955
1965
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1195
ECAL
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40
20
0
1955
1965
1975
1985
1995
Pasture
Sugar Cane
Range
Wetland
Vegetables
Citrus
Forest
Urban